Closeout Report on the DOE/SC CD-1 Review of the

Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) Project

Fermi National Accelerator Laboratory

July 14-16, 2015

Stephen W. Meador

Committee Chair

Office of Science, U.S. Department of Energy

http://www.science.doe.gov/opa/

U.S. DEPARTMENT OF ENERGY

Review Committee Participants

OFFICE OF SCIENCE

Stephen W. Meador, DOE/SC, Chairperson

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Beamline
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Lia Merminga, TRIUMF
Mike Syphers, MSU

SC2
Detectors
* Marty Breidenbach, SLAC
Cristiano Galbiati, Princeton
Harry Nelson, UCSB
Blair Ratcliff, SLAC
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SC3
Cryogenic
* Fabio Casagrande, MSU
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SC4
Conventional Facilities
* Brad Bull, MSU
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SC5
Environment, Safety and Health
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SC6
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Ted Lavine, DOE/SC	Eli Rosenberg, Iowa State
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LEGEND
SC Subcommittee
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Count: 24 (excluding observers)

** Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE), and Sanford Underground Research Facility (SURF)

U.S. DEPARTMENT OF ENERGY

Charge Questions

OFFICE OF SCIENCE

1. Does the conceptual design provide increased research capabilities envisioned in the mission need? Does the conceptual design report adequately encompass the entire scope of the project, facilities and detectors? Does the conceptual design satisfy the performance requirements recently recommended by the Particle Physics Project Prioritization Panel?

2. Do the conceptual design report and supporting documentation provide a reasonable basis for the stated cost range and project duration? In establishing the cost range for the DOE scope, has the project clearly identified all scope for which the DOE will be responsible? Is the cost and schedule for the non-DOE scope, to be provided as in-kind deliverables, in the LBNF/DUNE project consistent with historical CERN Core Costing rules?

3. Are ES&H aspects being properly addressed and are future plans sufficient given the project's current stage of development?

4. Is the project organized to successfully deliver all scope – DOE and in-kind? Are interfaces between the facility and the detector clearly delineated and appropriately managed? Does the proposed project team and staffing plan possess appropriate management experience, technical expertise, and laboratory support to produce a credible preliminary design leading to the technical, cost and schedule baseline required for CD-2?

5. Have all prerequisite requirements for CD-1 approval been satisfied? Is the project ready for CD-1 approval?

Subcommittee – Andrew Hutton, Lia Merminga, Mike Syphers

1. Does the conceptual design provide increased research capabilities envisioned in the mission need? **Yes** Does the conceptual design report adequately encompass the entire scope of the project, facilities and detectors? **Yes** Does the conceptual design satisfy the performance requirements recently recommended by the Particle Physics Project Prioritization Panel? **Yes**

5. Have all prerequisite requirements for CD-1 approval been satisfied? **Yes** Is the project ready for CD-1 approval? **Yes**

We believe the proposed systems will work as designed and will meet the goals of LBNF/DUNE.

Findings

- The conceptual design of the primary and neutrino beamlines has been completed and has remained unchanged for the last five years.
- Lessons learned from NuMI/MINOS and ANU/NO*ν*A have been incorporated into the design.
- The primary beamline design can accept 1.2 MW proton beams at 60 – 120 GeV initially.
- All components are either capable of handling 2.4 MW or can be upgraded to operate at that level.
- All components are designed for 42 MW-Year of radiation damage.
- Beamline components assumed to be outside DOE scope are:
  - Primary Beam dipole magnets and corrector magnets.
  - Neutrino Beam target prototype; instrumentation for target/horn; support module and carrier for target/baffle; support modules for horns; horn power supply; target shield pile hatch covers and cooling panels

Findings

- The primary beamline layout and engineering is very well advanced, and would be ready for a CD2 Review.
  - Beam extraction is essentially the same as for the NuMI beam line, and much of the beam line design concept is similar to NuMI.
  - A large portion of the team has worked on NO*v*A upgrades.
  - In most cases typical Fermilab components are being used for the project, either re-used from previous projects or will be constructed from existing well-established designs. All magnets have been specified; conceptual designs are complete.
  - A new BPM design (buttons) will be used for the beam line; most other instrumentation is replicated from NuMI. The high-power operation of LBNF may require a new choice for beam profile measurements.
- System Integration includes controls, interlocks, alignment, and installation coordination. Conceptual designs of all systems are complete and estimates fully developed. There is a convincing overall plan and competent staff.

Findings

- Extensive MARS optimization, including results from a genetic algorithm, has led to a new conceptual layout of the horns and target, with an associated increase in neutrino yield:
  - from **35 to 46** ν_m/GeV/m^2/yr @ 2.8 GeV, **+31%** at the first oscillation maximum
  - from **16 to 27** ν_m/GeV/m^2/yr @ 0.8 GeV, **+68%** at the second oscillation maximum
- The decay channel is now filled with Helium gas, increasing the neutrino flux by ~10%.
- The beam size at the target has been increased from 1.3 mm to 1.7 mm (sigma)

Findings

- Conceptual design for the LBNF neutrino beamline has been completed. Beamline installation is planned for March 2026.
- The two horns envisioned in the present concept utilize NuMI/ NO*v*A conductor design. Significant analysis effort has been expended to ensure capability at 1.2 MW operation. The support modules have been analyzed for 2.4 MW operation, and designed to last for the life of the facility.
- A workable preliminary conceptual design for the target capable of operating at 1.2 MW beam has been developed, which evolved from NuMI with modifications for higher power, with more cooling and larger spot/width. Stainless and aluminum components have been replacement with titanium and beryllium.
- An on-going vigorous R&D program is evaluating target design options. The experimental program carried out with outside collaborators (BLIP@BNL and HiRadMat@CERN) is particularly noteworthy.

Findings

- The target chamber, decay pipe, and muon absorber have all been upgraded to accept 2.4 MW beam operation.
- The target chase design has been upgraded to provide additional space allowing for further target and horn optimization (10 m longer and 0.6 m wider).
- Much effort has gone into the design for water containment and air release, and other ES&H radiological issues. The design goal is to contribute less than 30% of the total Fermilab limits.
- Radiological concerns and corrosion due to radiation byproducts have been evaluated and mitigated.

Comments

- We were impressed with the quality and depth of the presentations. The beam line design team is highly qualified and was well prepared. Many have worked on the previous neutrino beam lines and bring that world-leading experience to the table.
- The design is very mature, being based on 5 years previous work from LBNE and LBNO, and is well beyond the CD-1 level in most instances.
- The target and horn in the baseline design meet the requirements of CD-1. In our opinion optimization should continue along the lines that have already been demonstrated. For the project, this would be an excellent investment of R&D funds at this time that can lead to a significant increase in performance.
- Specifically, continued effort over the planned two year gap would be extremely beneficial for the target and horn optimization and design and could have a large payoff in overall performance.

Comments

- We were pleased to see the creation of a dedicated target R&D group and suggest that flux concentrator R&D be treated similarly.
- Work packages should be developed for complete sub-systems that can be offered to outside collaborators rather than isolated pieces of equipment. This will make collaboration more attractive, the results easier to track, and enhance the likelihood of success.
- Because of the long duration of the project, succession planning must be integrated into the overall planning.
- Horns were developed 35 years ago, and the time is ripe for attempting to develop a new technology for flux concentrators – a challenge for the new generation.

Recommendation

- Actively pursue further improvements to the target and horn layout with an overall goal of reducing the time to obtain first physics results.

2.2 Detectors

M. Breidenbach, C. Galbiati, H. Nelson,
B. Ratcliff, R. Rusack,

1. Does the conceptual design provide increased research capabilities envisioned in the mission need? Yes Does the conceptual design report adequately encompass the entire scope of the project, facilities and detectors? Yes Does the conceptual design satisfy the performance requirements recently recommended by the Particle Physics Project Prioritization Panel? Yes

5. Have all prerequisite requirements for CD-1 approval been satisfied? Yes Is the project ready for CD-1 approval? Yes

- **Findings**
- **Comments**
- **Recommendations**

Findings

- **Findings:**

1. The committee heard a large number of talks relevant to the DUNE detectors, but there was more interesting material and questions than could be fit in the allotted time.
2. The detector team has put in a great deal of effort in the short period since the collaboration was formed. The collaboration is growing and well engaged and led by a strong, well organized management team. An impressive CDR document has been produced and there is a large amount of other documentation detailing the status of the detector. Several tasks forces are being created to address important reconstruction and physics performance questions with the requirement to deliver preliminary and final reports in the next twelve to eighteen months. The committee greatly appreciates the interesting presentations and the lively and informative exchanges with the collaboration.

Findings

3. The near detector uses well validated detection techniques and its design is therefore rather advanced. Its standalone physics program is strong. Further simulation work is needed to quantify the impact of the present design on the systematics of the long baseline measurements, and the possible benefits of including additional nuclear targets.
4. The committee heard both technical descriptions and a budget and schedule drilldown for the Anode Plane Arrays.

Findings

5. From the Collaboration's responses to the committee's questions, it emerged that the physical parameter most critical for detector performance is electron lifetime. Its degradation would severely affect the ability to reach physics goals. Electron meanlife is likely to be affected by the standards adopted for leak checking and final cleaning of surfaces. The only measurement of meanlife within a cryostat with the same technology as DUNE is with the 35-tonne prototype. With an empty cryostat, the performance was borderline. The stated requirement for the leak rate of a single cryostat is 10^{-6} mbar×l/sec of helium equivalent leak.
6. No neutrino liquid argon Time Projection Chamber has so far operated for a significant exposure in a self-triggering mode.
7. Rejection of the 14MHz rate of 39Ar is required and challenging, as the threshold is just above the end of the 39Ar beta spectrum. There was no information on the expected rates for 222Rn contamination, which will surely be above the announced threshold, or on contributions from 238U and 232Th from the construction materials.

Findings

8. The far detector consists of four independent halls that will be equipped with separate 10 Ktonne detectors. The project is structured with the four cryostats as part of the LBNF project, with the detectors - cathode and anode planes etc. - are part of the detector project. The far detector (wbs 130.05) consists of the time projection chamber, the DAQ and monitoring, the installation and commissioning, the photon detector system and the cold electronics. Conventional facilities, cryogenics, and the cryostats are not part of the DUNE side of the project. Costs of the four detectors have been calculated on the basis of the cost of a 10 kTonne single-phase detector.

Findings

9. The DOE contribution to DUNE are for sub-components rather than for complete deliverables. For example half of the anode plane arrays are being made with DOE funds, with the remainder a non-US deliverable.

10. The detector group has an aggressive R&D program with several planned prototypes. A 35 ton detector will operate at FNAL and single phase and dual phase detectors are to be built and operated in a new test beam at CERN. Information from these and from ongoing experiments - MicroBoone etc. - will be used to understand many questions about the performance of large scale liquid argon TPCs.

Comments

- Comments:

1. The committee is reasonably convinced that DUNE has met the design maturity level required for CD-1, has exceeded it in many areas, but will be able to use profitably the time before CD-2 in 2019.
2. The reference photon detector design may not have adequate performance for non-beam physics, and its long term performance stability is unknown. The committee was shown that other plausible solutions, several of which are under R&D, seem quite likely to perform better. Costs and long term stability are not well understood in some of these alternative cases.
3. A common fund would increase management flexibility.
4. The cost drill down for the APA was quite good for this stage of the project. Managers will need schedules at a higher level than presently provided by P6.
5. It is not clear that the methods described for leak checking (penetrating dyes, ammonia test) will meet the requirements as stated.
5. Operation of prototype detectors on surface in a self-triggering mode will inform the trigger strategies for DUNE.

Comments

7. The strategy of having four separate halls in the facilities design allows flexibility on the long-term implementation of the project, beginning with the first 10 kT detector allowing the collaboration to have more than a single detector option. This has the added advantage that it can be used to attract new collaborators and allow for development of the detector.
8. The ideas behind the creation of the task forces are sound and their work will be essential to meet the requirements of CD2. We are concerned that the level of effort required to pull off these complex tasks will not be available in a timely manner. This could slow the decision process as choices for the detector design advance. Having a robust simulation environment will be essential to address questions of the scope of the project, which may arise if the detector construction budget is reduced.
9. Critical areas for the collaboration, such as computing infrastructure, are not part of the project and need a home.

Comments

10. Managing subsystems that are split across countries will be challenging, and particular attention must be paid to QA and interfaces.
11. It is important as the new collaboration expands that positions of responsibility are kept open to be filled by newcomers.
12. The organization of the collaboration is complex, with a complicated history evolving from LBNE to the “first U.S. International Mega-Science Project”. Management will be challenging, but the leadership both understands this well and is capable.
13. Costs for the detectors are substantially different under CORE and TPC DOE accounting, with no simple scale factor relating them.

Recommendations

- **Recommendations:**

1. Develop a performant, cost effective photon detection device to replace or confirm the reference design presented at this review. A new reference solution is expected this fall. This program and its follow-on R&D need to ensure that the devices are stable long term, and can be built at a reasonable cost. They will also need thorough testing both in standalone tests and at scale in the large prototypes. This work should be available for CD2.
2. Develop appropriate requirements for leak checking, for final surface cleaning and its verification, and for the allowable 222Rn, 238U, and 232Th contaminations. Evaluate the effects of backgrounds, including neutrons, on the nucleon decay science. This work should be available for CD2.
3. The DOE and the detector management need to work together to increase the US university participation within the project before CD2.

Committee Members: M.Howell, ORNL; F.Casagrande, MSU

1. Does the conceptual design provide increased research capabilities envisioned in the mission need? YES Does the conceptual design report adequately encompass the entire scope of the project, facilities and detectors? YES Does the conceptual design satisfy the performance requirements recently recommended by the Particle Physics Project Prioritization Panel? YES

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2.3.1 Findings

- The scope of the LBNF Cryogenics Infrastructure includes the design, procurement, fabrication, testing, delivery and installation oversight of four(4) 10 kton (fiducial mass) membrane cryostats to contain the liquid argon (LAr) and the time projection chambers (TPCs), and the comprehensive Cryogenic System that meets the performance requirement for purging, cooling down and filling the cryostats, acquiring and maintaining the LAr temperature within ±1 K around nominal temperature (88.3 K), and purifying the LAr outside the cryostats.
- The reference-design for the LBNF cryogenics Infrastructure encompasses the following components:
- Four 10 kton (fiducial mass) membrane cryostats (current budget is 2 cryostats)
  - each cryostat is composed of:
    - A free standing steel outer support structure including the top (warm vessel)
    - A membrane cryostat (cold vessel)
  - The cryostats are almost entirely non-DOE contribution.
- Receiving facilities for LAr and LN2 tanker trucks
- Transfer system to deliver gas argon and nitrogen from the surface to the underground cavern area
- Closed loop LN2 refrigeration system for condensing GAr
- Boil-off gas re-liquefaction equipment
- LAr-purification facilities
- Cryostat-purge facilities

2.3.1 Findings (cont.)

- Cryogenic system components are located in and around the surface building, in the Ross shaft and within the underground caverns located 1mile below grade.
- On the surface there will be a cryogen receiving station. A 50 m3 (69 tons of LAr capacity) vertical dewar will have two LAr truck connections to allow for receipt of LAr deliveries for the initial filling period. This liquid argon dewar serves as a buffer volume to accept liquid argon at a pace of about 5 LAr trailers (18 tons per trailer) per day during the fill period.
- Another 50 m3 vertical dewar and fill connection will be available near the liquid argon dewar. This dewar is used to accept nitrogen deliveries for the initial charging and startup of the nitrogen refrigerator.
- The Ross shaft contains the vertical pipelines connecting the surface equipment with the equipment in the cavern. The piping run consists of a gas argon transfer line and the compressor suction and discharge lines. At the bottom of the Ross shaft at the 4850 level, the piping exits the shaft and runs along a drift to the detector cavern.
- The central utility cavern at the 4850 level contains the rest of the nitrogen refrigerator (cold boxes), liquid nitrogen storage vessels, argon condensers are in the detector cavern, external liquid argon recirculation pumps, and filtration equipment. The nitrogen refrigerator equipment is located at the far end of the central utility cavern, away from Ross shaft.

2.3.1 Findings (cont.)

- The cryogenic cycle for nitrogen and argon is the same as CD1. The location of detectors is underground now compared to CD1: there were not pipes for Ross Shaft and all cryogenics were in surface facilities. No underground caverns.
- **Cryogenic Subsystems that have changed since CD-1**
  - Liquid Filtration (Purification)
  - Reliquefaction (Condensing)
  - Cryostat Filling
  - LN2 Refrigeration
- **Cryogenic Subsystems that have not changed since CD1**
  - LAr, LN2, Receiving Facility (Fill Station)
  - Insulation Purge
  - Cryostat Purge & Cool-down

2.3.1 Findings (cont.)

- **Cryostat changes since CD1**
- Location. Now at the 4850L of SURF.
- Physical dimensions and volume have changed:
  - From 28.6 m (L) x 15.6 m (W) x 16.0 m (H) to 62.0 m (L) x 15.1 m (W) x 14.0 m (H).
  - From 2 x 5 kton FM to 4 x 10 kton FM (**4 x 17.1 kton** = 68.4 kton total LAr)
- Support structure has changed
  - From concrete against the rock to steel self-supported.
- Value Engineering ongoing that may change the design:
  - VE-FD-026 Maintaining the temperature of the roof of the cryostat at 100K (DocDB n. 9456).
  - VE-FD-025 Locating the LAr pumps external to the cryostat (DocDB n. 9173.).

2.3.1 Findings (cont.)

- There is an ongoing important effort on cryostat prototyping with several cryostats being designed and built in the next 2-3 years:
  - WA105 1x1x3 in Building 182 at CERN → 18 m^3 LAr
  - SBND at Fermilab → 189 m^3 LAr
  - DUNE Single Phase test prototype in EHN1 at CERN → 485 m^3 LAr
  - WA105 6x6x6 in EHN1 at CERN→ 485 m^3 LAr
- – They all use the same membrane cryostat technology from GTT, albeit with different insulation thickness (ranging from 0.6 to 1.2 m).
- – They will all have a steel support structure, similar to the one being developed for the LBNF cryostat.
- – The cryostat prototyping is an essential effort to learn and understand the nuances of the construction process (at growing scale) of the cryostat (steel support structure and membrane) and apply lessons learnt to the construction of the LBNF cryostats.

2.3.1 Findings (cont.)

- It is assumed that entire cryogenic system infrastructure is split in responsibility between DOE and non-DOE partners. DOE partner is responsible for the surface level components: cryogenic receiving station, the surface level nitrogen compressors, and piping in the Ross shaft. DOE partner is responsible for the 4850L components: nitrogen refrigerators, nitrogen dewars, and boost compressors for the low pressure header. The non-DOE partners have responsibility of the components at the 4850L; two cryostats and detectors, the argon condenser systems, the argon purification and regenerations systems.
- There is currently no agreement in place with non-DOE partners.
- Process Controls design was not available
- Cryogenics Infrastructure is identified in CD3a as Advanced Long Lead procurement items on the Critical Path
- A significant time period exists between receipt of the nitrogen refrigerators and the commissioning of those refrigerators.

2.3.1 Findings (cont.)

- Only major risks that affect the project critical path were collected in the project risk registry. Smaller risks were not captured but additional risk assessments are planned.
- Equipment delivered to the site will have to be stored for a period of time prior to being installed in the mine. Staging areas and storage buildings are in the scope of the construction company.
- The cost estimate and schedule for the system is appropriate for CD-1. The level of detail will need to progress accordingly during the CD schedule.
- Cryogenic DOE cost $81113K
- Cryogenic Core Cost $108555K , 8Khrs
- Cryostat DOE Cost $3174K
- Cryostat Core Cost $116379K, 0K hrs
- Cryogenic Fluids Procurement DOE cost $49381K
- Cryogenic Fluids Procurements Core cost $66379K, 15Khrs

2.3.1 Findings (cont.)

- **Cryogenic systems Oxygen Deficiency Hazards (ODH) are assessed per**
  - Fermilab Environment, Safety and Health Manual (FESHM chapter 4240)
    - Requirements, peer reviews, safety panel review
  - SURF Environment, Health and Safety (EHS)
  - LBNF/DUNE has an Integrated Environment, Safety, and Health Management Plan (doc-10763)
- **ODH analysis was completed** and determined that all areas should be qualified as ODH-0 or ODH-1. Analysis was conducted assuming ventilation provided from existing SURF ventilation fans.
- **Other relevant FESHM Chapters**
  - 5031 Pressure Vessels
  - 5031.1 Piping Systems
  - 5031.4 Inspection and Testing of Relief Systems
  - 5032.5 Low Pressure Vessels and Fluid Containment
  - 5031.7 Membrane Cryostats
  - 5032 Cryogenic System Review
  - 5034 Pressure Vessel Testing
  - Other National and International standards are referenced by FESHM, including ASME

2.3.1 Findings (cont.)

- Power reliability
  - SURF has reliable electric power from three independent supply sources and additional local back up generators
- Few Argon suppliers are identified near SURF. Air Separation Units in the Chicago area and the gulf coast were identified as the most important supply sources.
- "Over the road trucking" is foreseen to be the primary transport method of delivery
- The initial usage of LAr is equal to approximately 3% of the US annual capacity.
- The demand for Ar is approaching the supply available with little capacity increase being planned until 2021.
- Potential source of Argon has been identified in a plant in Beulah, ND owned by Basin Electric but it requires development.
- Argon pricing is directly related to the distance it is trucked. Of possible sources, Argon from Beulah, ND would be the cheapest while argon from New Orleans, LA is most expensive. The price is different by a factor of about 2.

2.3.1 Findings (cont.)

- Recommendation list from previous reviews was provided for cryogenics and cryostat. Two recommendations are past due.

2.3.2 Comments

- Cryogenic system requirements flow from LBNF/DUNE requirements spreadsheet
- The design is appropriate for this stage of the project
- Prototyping schedule milestones should be integrated with project to make sure lessons learned are captured in time
- Design should have commissioning and operation inputs from the early stages
- Clearly defined deliverable and ownerships of the subsystems should be defined as early as possible
- Prior to CD-3A, the scope of each partner must be finalized. Efforts should be made to accelerate a formal agreement with non-DOE partners.
- Reevaluate the Advanced Long Lead procurement plan for the cryogenic infrastructure considering logistics and maintenance complications , warranties and acceptance implications due to long storage times required after delivery
- Process Controls Design is not as mature as the the rest of the cryogenic design

Comments 2.3.2 (Cont.)

- Risks to cryogenic fabrication, installation and commissioning such as weather delays, potential evacuations from the mine, injuries, should be captured in the project risk registry as the project progresses to CD-2.
- ODH analysis should be updated as final ventilation designs are completed. Of particular interest is the lower levels in the detector cryostat areas.
- A logistical plan of transporting equipment from the vendor to storage facilities to the mine must be formalized by CD-2.
- When engaging refrigeration vendors, ensure commissioning support is available over an extended period of time.
- Secure argon supply and ensure adequate contingency is available for price fluctuations that may occur as demand approaches supply capacities.
- Investigate whether the plant in Beulah, ND is a potential source of Argon for this project.

2.3.3 Recommendations

- Define the critical engineering controls in relation to the oxygen deficiency hazard (i.e. ventilation fans, ventilation instrumentation, ODH monitors) CD2
- Key positions in the cryogenic operations team that will commission maintain and operate the cryogenic system must be identified and should be involved in the detailed design of the system. (CD-3a.)
- Controls Resources must be dedicated immediately to the project
- Respond to recommendations by due date

3. Conventional Facilities

Jack Stellern, ORNL and Chris Laughton

Subcommittee 4

1. Does the conceptual design report adequately encompass the entire scope of the project, facilities and detectors? Yes.

5. Have all prerequisite requirements for CD-1 approval been satisfied? Is the project ready for CD-1 approval? Yes.

Findings

- **CF understands the importance of finalizing interface agreements with the technical groups and is working on the far site Interface Control Documents.**
- **The far site design has been awarded and 30% preliminary design and estimate is completed. Separate contracts will be awarded for the near and far sites CF design and construction.**
- **The project intends to use a construction manager at risk or CM/GC for both the near and far sites.**
- **Fermilab has a DOE approved EVMS process.**

Findings

- **Near Site**
  - **The Conventional Facility design concepts are based on proven engineering solutions and benefit from NuMI Lessons Learned.**
  - **Key elements of the civil design are;**
    - **Slurry wall technology is used to minimize the risk of displacement of Main Injector structures adjacent to the extraction point.**
    - **Embankment is used to keep beamline structures at or near-grade and minimize excavation work below the groundwater table.**
    - **Embankment pre-load is used to ensure that long term settlements are low and can be managed during construction.**
    - **Systematic pre-grouting is used to reduce excavation water inflow at depth.**

Findings

- **Far Site**
  - Based on direct observation from SURF and review of early site investigation data the host rock mass (Poorman Formation) should be suitable for the LBNF caverns (25m span).
  - The concept design calls for the use of standard reinforcement/liner systems (bolts, cables, shotcrete).
  - LBNF construction work will be supported by the Ross shaft.
    - The Yates Shaft is undergoing "Top Down" ground and timber frame maintenance work.
    - The Ross Shaft is undergoing ground stabilization and steel frame replacement work.
    - SURF will restore the Yates and Ross Hoist systems (Winders, Headframes, Ground Support and Guide Frames) to their design capacity.

Comments

- **The CF conceptual design report is well developed and includes the entire scope of the facilities for the project.**
- **The CF team is experienced and established at the near and far site. Some additional personnel needs have been identified and will be filled.**
- **Far site design and construction is the priority in the CF schedule. The far site design has been awarded to ARUP. ARUP is an experienced designer that will bring the necessary expertise to the design team. Separate contracts is the correct approach for the design and construction procurements based on the location separation and the schedule gap between the activities.**
- **CM/GC contract will be the best procurement method for the construction efforts. This method will bring in large experienced high quality companies in to bid on the construction.**

Comments (continued)

- CM/GC reduces the possibility that high bids will surprise the project because the CM/GC design support staff and subcontractors perform constructability reviews as the design progresses and provide independent construction estimates.
- This will be the first CM/GC procurement for the Fermilab so there will be a learning curve but they have reached out to other DOE labs that are experienced with CM/GC's to guide their approach and procurement requirements.
- The far site preliminary design will be complete in August 2015 and the estimate will be completed in September. The best scenario would be for the CM/GC contract to be awarded in August to prepare an independent construction estimate based on the preliminary design but this is not possible considering the current status of the procurement. The project and DOE should work together closely to minimize the time needed for contract bid and award so the CM/GC can provide comments and guidance as early as possible into the ARUP final design.

Comments

- **The project does not intend to use their EVMS system to track project performance until before CD-2. I suggest that the project reevaluate that decision and use EVMS starting early in the project and ensure that project performance and variances are reviewed monthly.**

Comments

- **Near Site**
  - **Strong Team with an in-depth knowledge of the site and facilities.**
  - **Ground units are relatively well-known from previous excavation and site investigation work.**
  - **Selected mitigation measures are appropriate for the expected range of site conditions.**
  - **Similar excavations have been successfully mined in the same ground units.**
  - **Construction activities at the Near Detector site are likely to disturb the neighboring residential community.**

3. Conventional Facilities

Jack Stellern, ORNL and Chris Laughton

Subcommittee 4

Comments

- **Far Site**
  - **Strong Team with an in-depth knowledge of the site and facilities.**
  - **The Team has identified many of the challenges associated with undertaking large-scale drill and blast operations on the 4850 level. The need for good coordination of DUNE, LBNF and SURF underground activities is also recognized.**
  - **Review teams have identified the need for additional space to support drill and blast operations on 4850. Excavation of this space can reduce the possibility of bottlenecking and interference.**
  - **To address interface and coordination issues DUNE, LBNF and SURF will hold a joint Logistics Workshop in August.**
  - **The Team acknowledges the critical importance of shaft availability to LBNF success. The Team is committed to performing regular shaft system inspections and maintenance work.**
  - **Ground movement at the Ross Shaft pillar zone will be monitored.**

Recommendations

- **Near Site - Continue to interact with Near Detector neighbors to develop common expectations and work to mitigate off site impacts. Consider using mechanical excavation techniques.**
- **Far Site - Continue a strong focus on defining underground user interfaces and logistics planning.**
- **Far Site - The project and DOE should work together closely to minimize the time needed for the CM/GC contract bid and award.**
- **Approve CD-1 Refresh**

3. Are ES&H aspects being properly addressed and are future plans sufficient given the project's current stage of development?
   Yes

5. Have all prerequisite requirements for CD-1 approval been satisfied? Is the project ready for CD-1 approval?
   Yes

4.1 Findings (Conventional ESH aspects)

Documentation supporting CD-1 is complete

- Preliminary Hazards Analysis Report
- Integrated Safety Management Plan
- QA Plan
- NEPA (strategy)
- Safeguards and Security (requirements)

Documentation supports identification and mitigation of Project hazards at both near & far sites.

ES&H staff assigned to the Project are experienced and competent. Institutional ES&H & Partner laboratory support has been effectively used.

Oxygen Deficiency Analyses have been completed for underground areas

- Follows FESHM 4240 & other required internal standards

Lessons Learned from previous construction experience (NuMI, MINOS) have been incorporated into the design.

The Environmental Assessment (EA) for activities at both the near and far sites has been developed and issued for public comment. Comments are being addressed.

When the cavities are outfitted with the detectors, only a narrow walkway will separate the exoskeleton structure (outer detector frame) from the cavity wall.

4.1 Findings (Far Site Facilities)

The far-site ventilation system is a key consideration in ODH, Smoke and Worker Safety & Health and will utilize the existing facility air as much as possible with minimal modifications.

- Fresh air to the LBNF cavities and the utility drifts will be provided from the Yates and Ross shafts, exhausting from the LBNF cavities and utility drifts via the 4850L, traveling through a complex set of passages to the 3600L where it will enter the Oro Hondo shaft.
- The project plans to replace the fan on the Oro Hondo shaft and to support infrastructure activities (ground support) for the existing ventilation circuit.

Far-site SURF operating cost are listed at ~$20 million. This includes the Ross Shaft rehabilitation, infrastructure maintenance, shaft operations, and a number of other important operational activities.

ESH through design is well established via development of Scientific Objectives, which are then driven through to Engineering Specifications

Not all risks that could affect construction and operational activities have been identified and documented in the risk registries.

A cross walk table looking at 10CFR851 requirements and SURF ESH requirements has been developed.

4.2 Comments

Potential high risk issues do not appear on the project's risk register that could impact LBNF/DUNE project schedule. If the risk register represented a robust collection of far-site risks, a systematic methodology could be applied in understanding and reducing risk as appropriate i.e. water inundation, exhaust shaft maintenance, return air entry maintenance, redundant power supply, Yates shaft refurbishment, etc.

In the absence of an accurate ventilation model, the exact demand of the far-site facility on the SURF ventilation system is not fully realized. This represents a risk to the project as it will require the existing ventilation system to perform consistently at a high capacity. Potential reductions in the ventilation capacity of the Oro Hondo shaft, #5 shaft, or the extensive return air passages could threaten the project schedule.

There is a significant risk for water impoundment above the 4850L. Controlling the risk of an unplanned discharge of water into the 4850L, the project has initiated a detailed assessment of water transport and retention conditions. A site-wide assessment of the water impoundment sources listed above is done on an annual basis with spot analysis completed as needed. Through this analysis, the project has devised a plan to capture a significant concentration of water at the 1850L and divert it to the #5 shaft. This effort was begun in 2013 and is scheduled to be completed in 2016. While this activity is commendable, it is not clear that it will significantly reduce the risk of inundation.

4.3 Recommendations

1. Complete the ventilation model and provide a plan to assess the risks associated with potential restrictions to the exhaust ventilation circuit; Oro Hondo shaft, #5 shaft, and return air passages (prior to the CD-3A)
2. Conduct a formal risk assessment of the inundation hazard and develop a comprehensive plan to mitigate this risk. Additionally, remote continuous monitoring of key control structures should be considered (prior to CD-3A)
3. Develop a list of commitments stemming from the EA that the Project can use to ensure compliance (by CD-3A)
4. Validate the ODH assumptions and analysis through the Cryogenic Safety Subcommittee established for this Project (by CD-3A)
5. Identify and document in the Far-Site risk registry, single point failures that could affect construction and operational activities. (by 100% design)

5. Cost and Schedule – Subcommittee 6

A. Mennona/BNL, M. Reichanadter/SLAC,
B. Thibadeau/ORNL

2. Do the conceptual design report and supporting documentation provide a reasonable basis for the stated cost range and project duration? In establishing the cost range for the DOE scope, has the project clearly identified all scope for which the DOE will be responsible? Is the cost and schedule for the non-DOE scope, to be provided as in-kind deliverables, in the LBNF/DUNE project consistent with historical CERN Core Costing rules?

   Yes, the LBNF/DUNE scope is supported by a comprehensive CDR consistent with the Threshold and Objective KPPs, and supported by a resource loaded preliminary baseline. All DOE and non-DOE scope is included in the preliminary baseline, and is consistent with LHC (CERN) costing practices.

5. Have all prerequisite requirements for CD-1 approval been satisfied? Is the project ready for CD-1 approval?

   Yes.

5. Cost and Schedule – Subcommittee 6

A. Mennona/BNL, M. Reichanadter/SLAC,
B. Thibadeau/ORNL

Findings

- The LBNF/DUNE project team presented a preliminary performance baseline with:
  - TPC cost range currently set at $1,255M – $1,727M
  - TPC point estimate at $1,457M, using standard DOE accounting
  - Project completion (CD-4b) projected at August 2028, with 31 months of float from the project's early finish date.
  - Contingency is $344,435k (34% on remaining work)
- Development of the preliminary baseline includes the following components:
  - Actual costs to date
  - Bottoms-up Basis of Estimate (developed by CAMs)
  - BOE Uncertainty Assessment as per Project Office guidance (assessed by CAMs)
  - High level Cost risk assessment based upon Monte Carlo of Risk Registry (assessed by Project Office)
- Accounting system (CORE) has been established to uniformly assess in-kind contributions from each LBNF/DUNE international partner. CORE accounting methodology excludes contingency, escalation, and other factors typically included in a DOE estimate.

5. Cost and Schedule – Subcommittee 6

A. Mennona/BNL, M. Reichanadter/SLAC, B. Thibadeau/ORNL

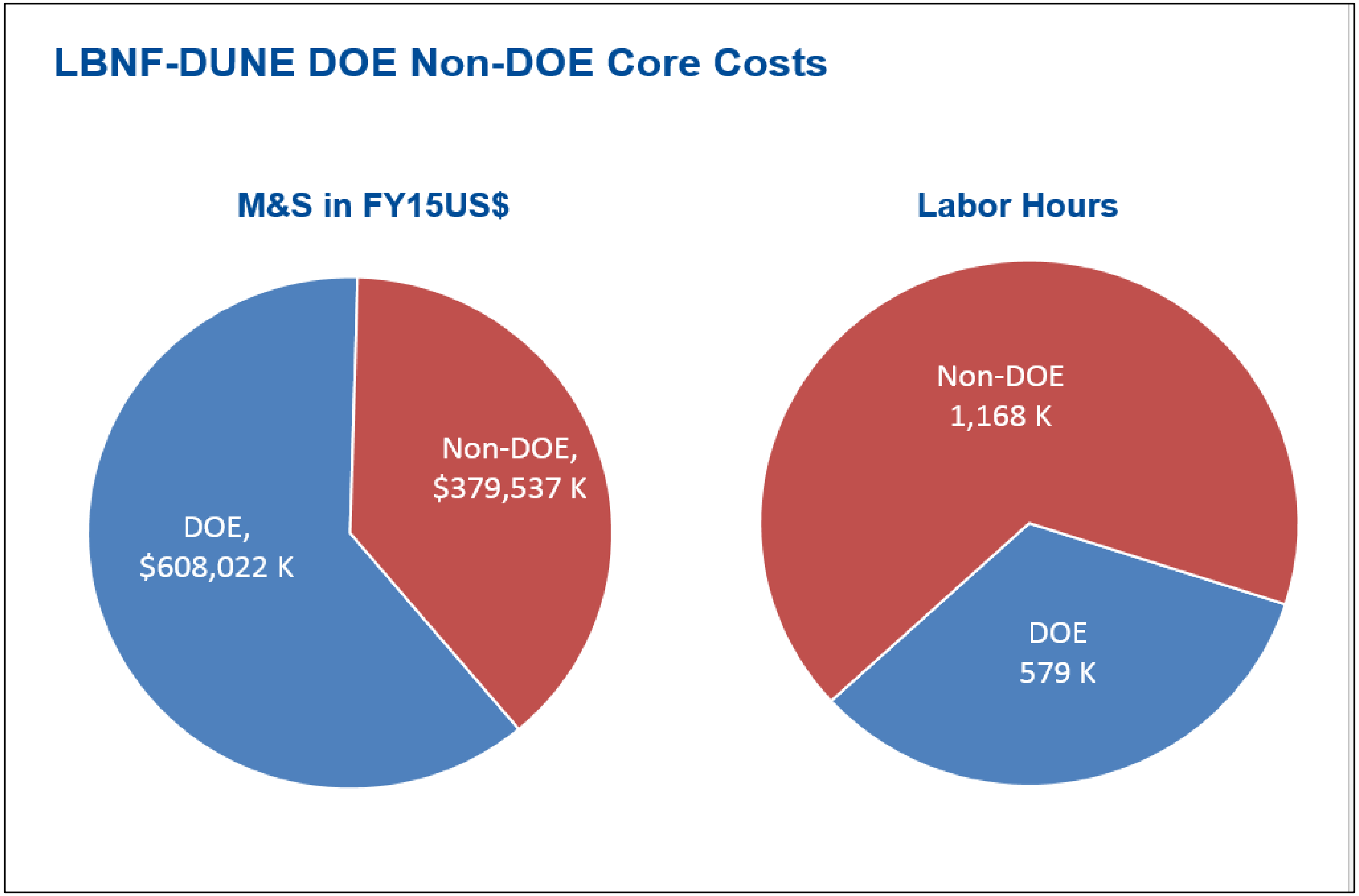
Findings

- LBNF and DUNE, although structured as separate projects, are managed in eight P6 schedule files linked by milestones into a single integrated schedule.
- The LBNF/DUNE resource-loaded schedule consists of 9,814 activities, 102 Control Accounts which are managed by 47 CAMs. Most Control Accounts are at WBS Level 4 or 5.
- Project baseline is costed in $FY15. Escalation and labor rates were provided through the Fermi Budget Office. Reduced overhead rates for LBNF/DUNE labor and M&S are in place.
- The Level of Effort percentage on the DOE funded effort ~12%. A large fraction of scientists are zero-cost to the project (supported via HEP Base Program). The Project's DOE scope of work will use EVMS to measure progress prior to CD-2. Non-DOE scope will use milestones to monitor progress. The DOE and non-DOE scope are both included in the integrated schedule.
- The Project has applied a risk-based Monte Carlo analysis to assess the need for schedule contingency.

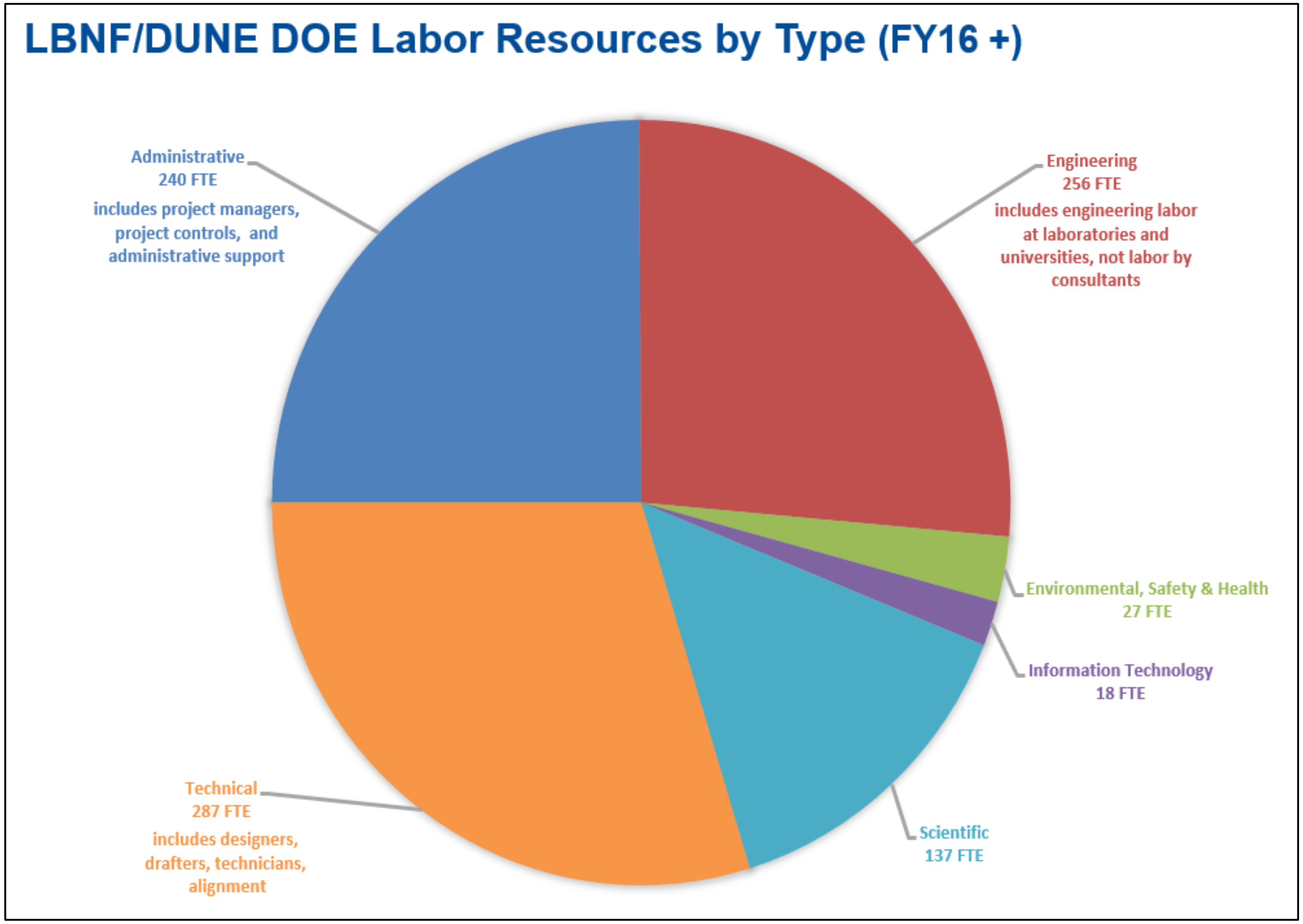
Findings

- A dedicated procurement team is planned for LBNF/DUNE with a direct charge to the project at certain $ value.
- The project is planning to reorganize the WBS structure to match the new LBNE/DUNE structure.

Findings (Back-Up Detail)

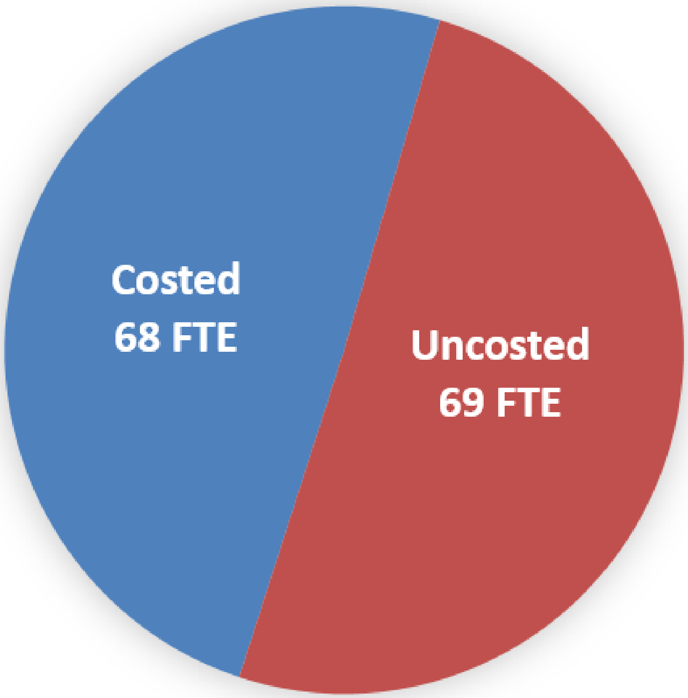


Findings (Back-Up Detail)



Findings (Back-Up Detail)

LBNF DOE Costed / Uncosted Scientist (FY16+)



All scientists hours are to be captured in the RLS. Scientists are costed to the project according to LBNF Project's implementation of the Fermilab policy and DOE OHEP guidance for charging scientist effort.

Scientists are costed, except:
- Scientists for collaborating universities
- Scientists from national laboratories, who are part of science collaboration, working on experimental portion and not in a management role.

Uncosted scientist effort uses $0 rate.

Comments

- The committee found the preliminary baseline to be complete and comprehensive. In some areas, maturity is beyond CD-1.
- Drill-downs into the cost and schedule estimates were found to be acceptable. Some improvements can be made, however there were no material errors or omissions.
- The CAMs were knowledgeable in their work scope and actively engaged in the project. The Project Controls team is experienced and has a strong presence within the project. Responses to requests for information were prompt and thorough.
- Assumptions around risk assessment and cost/schedule contingency needs appear optimistic, particularly in areas such as labor productivity, partner/vendor performance, and external conditions (weather, logistics, equipment availability). This is reflected by the relatively low 8% contingency assigned to the “top level risks”. The project should reevaluate the project’s overall cost contingency based upon a realistic risk assessment that could more appropriately account for “unknown unknowns”.

Comments

- BA-BO profile through FY19 is insufficient to cover the planned work with a sufficient contingency reserve. The Project should identify and quantify non-critical path work which can be delayed if additional contingency in the early years becomes necessary.
- The preliminary schedule is limited by the funding profile. A technically limited schedule could save ~$50M in DOE cost (1,408M vs. 1,457M) and approximately 2 years on beamline delivery.
  - Also allows the Near Site work to continue without the planned slowdown in FY16-FY17.
  - Any additional funding in FY18 improves the overall TPC <u>and</u> the BA-BO profile in the early years.
- The funding profile does not include OPC for commissioning and project closeout in the out-years. This should be reevaluated.
- While Fermilab recognizes the Host Lab should be prepared to solve cash flow problems within its non-DOE partners, there is not a plan today. The project should consider its options to managing cash flow issues now, prior to finalizing the agreements with its non-DOE partners.

Comments

- It was not clear to the committee that a CD-4a milestone to mark the “completion of cavern excavation and supporting utilities” was necessary. Consider a Tier 2 milestone instead.
- The upper bound of the cost range is ~18% above the current point estimate. Given the duration of project and with CD-2 ~4years out, an upper bound of ~35% above the point estimate may be more appropriate.
- Schedule contingency (float) on remaining work is ~23% on CD-4b. Given the long duration of remaining work (~11.5years) this may not be adequate. Adding another year of float would increase this schedule contingency to ~31%.
- The Project does not plan to implement its EVMS system until just before CD-2. This may be problematic given that CD-2 is ~4 years out and a significant amount of work (~30%) will be approved at CD-3a and CD-3b. To ensure the management team can adequately manage its work scope, consider reporting progress using EVMS at CD-3a and beyond.
- The 47 CAMs on LBNF/DUNE have not received formal EVMS training. The Project should work closely with FNAL’s Project Management Office to make some progress in this area.

A. Mennona/BNL, M. Reichanadter/SLAC, B. Thibadeau/ORNL

Recommendations

- Prior to CD-1:
  - Work with HEP to best optimize the LBNF/DUNE funding profile
  - Reprogram the profile to include sufficient OPC in out years
  - Reevaluate the BA-BO profile to ensure contingency can be made available in the early years. Quantify the amount of work that can be delayed to free up budget, without affecting the critical path
  - Reevaluate the overall project contingency after conducting a realistic assessment of the projects risk exposure
  - Reevaluate the cost range after determining the optimum funding profile
  - Reevaluate the CD-4b date after optimizing the funding profile and schedule logistics
  - Determine if a Tier 2 milestone could replace the proposed CD-4a milestone
- Work with the FPD and OPA to determine the best approach to measuring progress from CD-3a through CD-2
- Begin conducting EVMS training for all CAMs as soon as possible
- FNAL consider options to address cash flow issues with non-DOE partners
- Proceed to CD-1 Refresh approval

5. Cost and Schedule – Subcommittee 6

A. Mennona/BNL, M. Reichanadter/SLAC, B. Thibadeau/ORNL

PROJECT STATUS		
Project Type	MIE / Line Item / Cooperative Agreement	
CD-1	Planned: 1Q/2013	Actual: 10-Dec-2012 (A)
CD-1R	Planned: 1Q/2016	Actual:
CD-3a	Planned: 2Q/2016	Actual:
CD-3b	Planned: 3Q/2018	Actual:
CD-2/ 3c	Planned: 1Q/2020	Actual:
CD-4a	Planned: 1Q/2024	Actual:
CD-4b	Planned: 4Q/2029	Actual:
TPC Percent Complete	Planned: 7%	Actual: 7%
TPC Cost to Date	$97M	
TPC Committed to Date	$103M	
TPC	$1,457M	
TEC	$1,367M	
Contingency Cost (w/Mgmt Reserve)	$344M	34% to go
Contingency Schedule on CD-4b	31 months	23%
CPI Cumulative		
SPI Cumulative		

6. Management

Sub-committee 7

- Kurt Fisher (DOE/SC)
- Howard Gordon (BNL)
- Dan Green (Fermilab Emeritus)
- Jim Krupnick (LBNL retired) - chairperson
- Lynn McKnight (TJNAF)

6. Management

Findings

- TPC is $1.457B; Actual costs through May, 2015 are $97M.
- Two-thirds of the total project cost is M&S.
- Cost contingency is $344,435K or 34% of the to-go costs.
- The Project team has identified a construction start in FY 2017 that allows science to be begin in 2024.
- Schedule contingency is 24 months float on CD-4a; 31 months on CD-4b
- Scope contingency of approx. $50M has been identified.
- The LBNF Work Breakdown Structure (WBS) is being updated to align with current scope.
- The LBNF project will use Earned Value (EV) for the US portion and milestones to measure progress on non-DOE partner contributions.
- A high-level agreement with CERN has been signed.
- Sources for the in-kind (non-DOE) contributions are being pursued.

6. Management

Findings (cont)

- "CORE" costing technique has been adopted for international partners.
- Total cost estimate was developed in CORE accounting for entire international LBNF/DUNE Project: 988 M$ and 1.7 Mhrs
- The Resource Loaded Schedule (RLS) contains over 10,000 activities; in-kind work milestones will be added as they are identified.
- The LBNF / DUNE project has numerous internal committees and boards (RRB, PMB, EFIG) roles and responsibilities exist in several documents, however, no stand alone charters for these groups have been established.
- A new LBNF project director has been selected; hiring process almost complete.
- LBNF is in the process of issuing a construction RFP for the FS CF.
- Management's expectation is that "collaboration partners will deliver" their respective scopes of work.
- The project plans to add 2 procurement staff by end of 2015, and 2 more in FY16.

6. Management

Comments

- **LBNF/DUNE embodies a high level of management challenge**
  - Transition from LBNE
  - First International megaproject hosted by US
- **Fermilab management, including the Lab Director, is fully engaged in LBNF/DUNE in a positive way.**
- **Very (very) strong management team members in place on both projects; also good news that full-time LBNF Project Director about to start**
- **It is impressive that the DUNE collaboration has already made significant progress given that it met for the first time at Fermilab in April. It is important to maintain that momentum.**
- **There is a strong commitment to regular and substantive communication both within, and between, LBNF and DUNE.**
- **For example, EFIG has already proved productive.**
- **Strong link demonstrated between science objectives & detector specifications**

6. Management

Comments (cont)

- Encourage vigorous ongoing effort to secure non-DOE contributions.
- Partners delivered promised in-kind contributions in recent HEP international science projects.
- Contributions from another domestic funding agency would provide broader financial support for DUNE Project.
- We encourage DUNE’s goal of keeping members of former LBNE Collaboration deeply involved while helping new members of the Collaboration find meaningful roles.
- An active recruiting of DUNE collaborators now, in the design phase, is important and should be pursued vigorously.
- DUNE should consider simplifying organization; for example, combining technical board, executive committee, and computing software/physics coordinators.
- Having the DUNE Spokespersons in the EFIG is critical to maintaining focus on DUNE’s science goals.

Comments (cont)

- Systems Engineering, aided by existing Project Engineers, is ramping up and should move forward expeditiously. Will need local expertise and support.
- The DUNE far site detectors are similar to a spacecraft in the sense that once deployed, the detectors will need to operate almost without failure or maintenance for 30 years. This will require a robust commitment to Quality Assurance. MOUs with partners will need careful definition of QA requirements.
- Full-time QA manager should be hired as soon as possible.
- Additional Procurement staff are to be hired this year; need the Procurement Manager as soon as possible.
- CD3a plans appear carefully crafted; Accurate interface definition between conventional facilities and DUNE is critical.
- Adequate scope contingency should be identified prior to CD-2 when the non-DOE contributions will have been well defined.
- WBS should be updated ASAP

6. Management

Comments (cont)

- Concern about the availability of resources in the future, both staff and infrastructure, given the number and scale of projects planned for Fermilab. To help ensure successful outcomes, the Lab should prepare a comprehensive staffing and critical resource plan.

Recommendations

- Revisit procurement staff requirements semi-annually to address changes in volume of procurements; allow for time to train new staff
- Fill critical positions asap
- Proceed to CD-1 Refresh……

6. Management

Question 4

- Is the project organized to successfully deliver all scope – DOE and in-kind? Yes. Organization in place; must garner sufficient international resources
- Are interfaces between the facility and the detector clearly delineated and appropriately managed? Yes. Processes are in place; additional staff resources needed.
- Does the proposed project team and staffing plan possess appropriate management experience, technical expertise, and laboratory support to produce a credible preliminary design leading to the technical, cost and schedule baseline required for CD-2? Yes. Strong existing project team members with strong lab support; critical hires important for next phase.

Question 5

- Have all prerequisite requirements for CD-1 approval been satisfied? Yes.
- Is the project ready for CD-1 approval? Yes.